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AN EVALUATION OF REGISTERING IMAGE GRADIENTS WHEN MATCHING INFR--ETC(U)
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An evaluation of registering image gradients when matching infrared imagery to panchromatic imagery

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Michael A. Crombie

JANUARY 1981

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A method for calculating corresponding points between infrared imagery and panchromatic imagery using the image gradients and two vector functions is evaluated. The results of the study demonstrate that the method is not satisfactory for mapping.

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PREFACE

The work covered by this Research Note was conducted by the Computer Sciences Laboratory (CSL), U.S. Army Engineer Topographic Laboratories (ETL), Fort Belvoir, Virginia. It is part of an effort carried out in CSL on digital image analysis under Project 4A762707A855. Studies were conducted by Michael A. Crombie with computer programing assistance by James Miller and Robert Rand.

The work was performed under the supervision of D. E. Howell, Chief, Information Sciences Division; and L. A. Gambino, Director, Computer Sciences Laboratory.

COL Daniel L. Lycan, CE was Commander and Director and Mr. Robert P. Macchia was Technical Director of the Engineer Topographic Laboratories during the study and report preparation.

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AN EVALUATION OF REGISTERING IMAGE GRADIENTS WHEN MATCHING INFRARED IMAGERY TO PANCHROMATIC IMAGERY

INTRODUCTION

The sl. ırtcomings of conventional correlation methods when registering infrared (IR) imagery to panchromatic (PANC) imagery were demonstrated in a pervious U.S. Army Engineer Topographic Laboratories (ETL) Research Note.[1] Conventional correlation methods pertain to area correlation; wherein, the linear correlation coefficient of statistics is used as the measure of similarity. In the referenced ETL Research Note, other techniques, for example techniques that exploit image structures, were suggested for dissimilar image registration. The purpose of this report is to evaluate the method of using the image gradient rather than image intensities for image registration.[2] Two vector functions of the corresponding image gradients are used as measures of similarities.

NUMERICAL EXPERIMENT

In this report, the approach was to evaluate the suggested process with the same imagery used in the referenced ETL work and, if the initial tests showed promise, to expand the effort using a variety of scenes and scales. The pertinent exposure and scan parameters are given in the referenced ETL research note.

---

[1] M. Crombie, *An Evaluation of Conventional Correlation Methods When Matching Infrared Imagery to Panchromatic Imagery*, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, ETL-0195, August 1979, AD-A076 111.

[2] R. Hudgin, "Image Matching Using Structure Information," *SPIE*, Vol. 117, 1977, pp. 126–131.

GRADIENT IMAGE. A gradient image is constructed from a digital image of intensities by replacing each pixel gray shade value with components of the corresponding gradient vector (see figure 1).

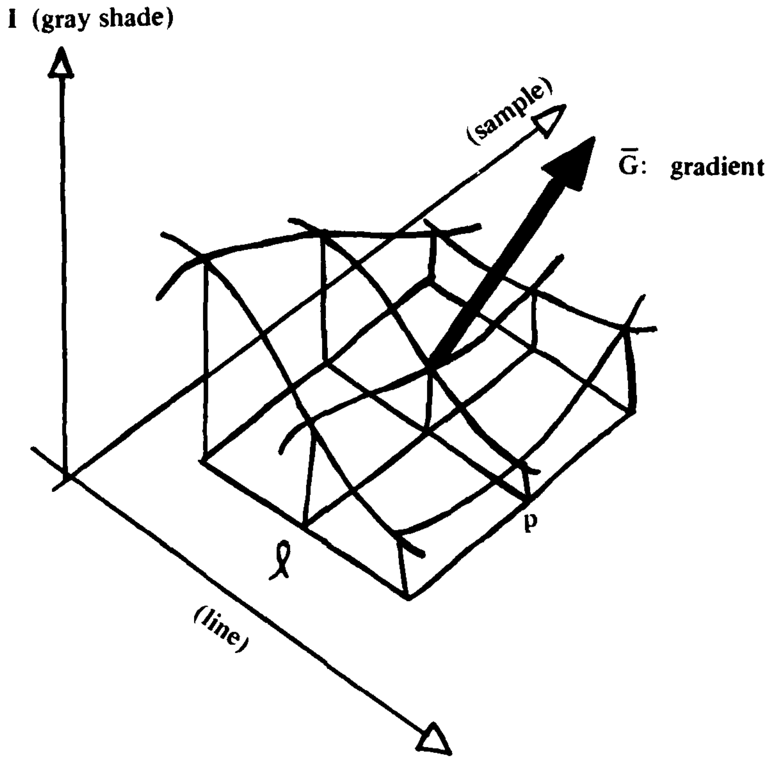


FIGURE 1. Gray Shade Gradient Function.

The two gradient components are estimated by fitting a plane at pixel (ℓ, p), using the gray shade value at (ℓ, p) and the four-corner gray shade values around (ℓ, p). The component estimates are

$$G_{\ell} = \frac{1}{2} \left[I_{\ell+1,p} - I_{\ell-1,p} \right]$$

$$G_{p} = \frac{1}{2} \left[I_{\ell,p+1} - I_{\ell,p-1} \right]$$

CORRELATION MEASURES. The conventional correlation measure of similarity is

$$R = \frac{\Sigma\ (I_1 - \bar{I}_1)\ (I_2 - \bar{I}_2)}{\sqrt{\Sigma\ (I_1 - \bar{I}_1)^2 \quad \Sigma\ (I_2 - \bar{I}_2)^2}}$$

where I_J represents a gray shade value from the J^{th} image, and $\bar{I}_J$ represents the window average.

A candidate point for matching is defined as the center of a window of pixel values. In practice, a point is defined on the first image (J = 1) and a correlation value is computed at an estimated match point on the second image (J = 2). A set of correlation values are computed by moving the window of gray shades about the match point estimate. The match point is defined to be at the location on the second image where the generated correlation function is maximum. A correlation function along one line is presented in figure 2.

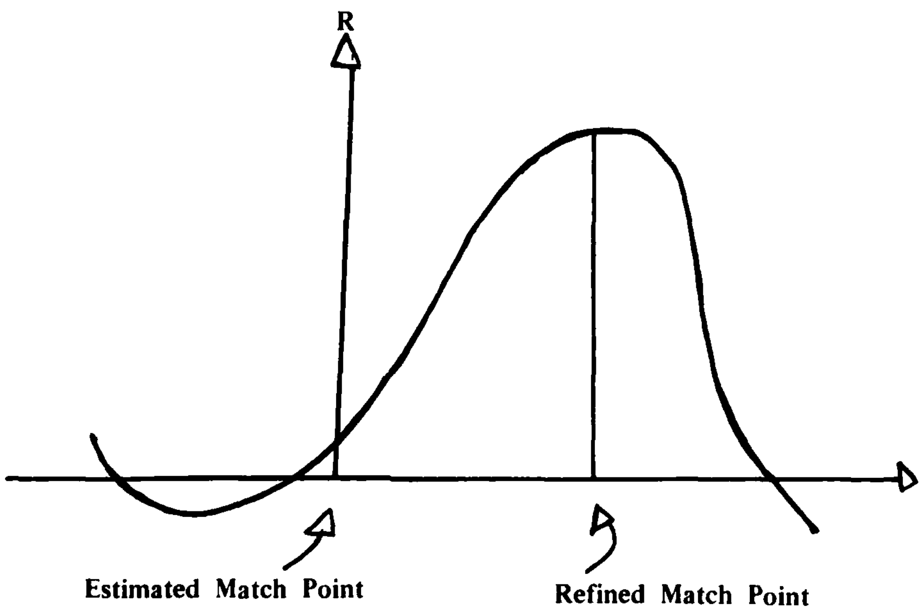


FIGURE 2. Conventional Correlation.

The two measures of similarity used in the gradient matching technique are the scalar product and the absolute value of the cross product:

$$R_s = \Sigma\ \bar{G}_1 \cdot \bar{G}_2$$
$$R_c = \Sigma\ |\bar{G}_1 \times \bar{G}_2|$$

where as before, the numerical subscript pertains to the image, and the summation sign pertains to the process of accumulation over the specified window.

The two vector correlation functions are shown in figure 3.

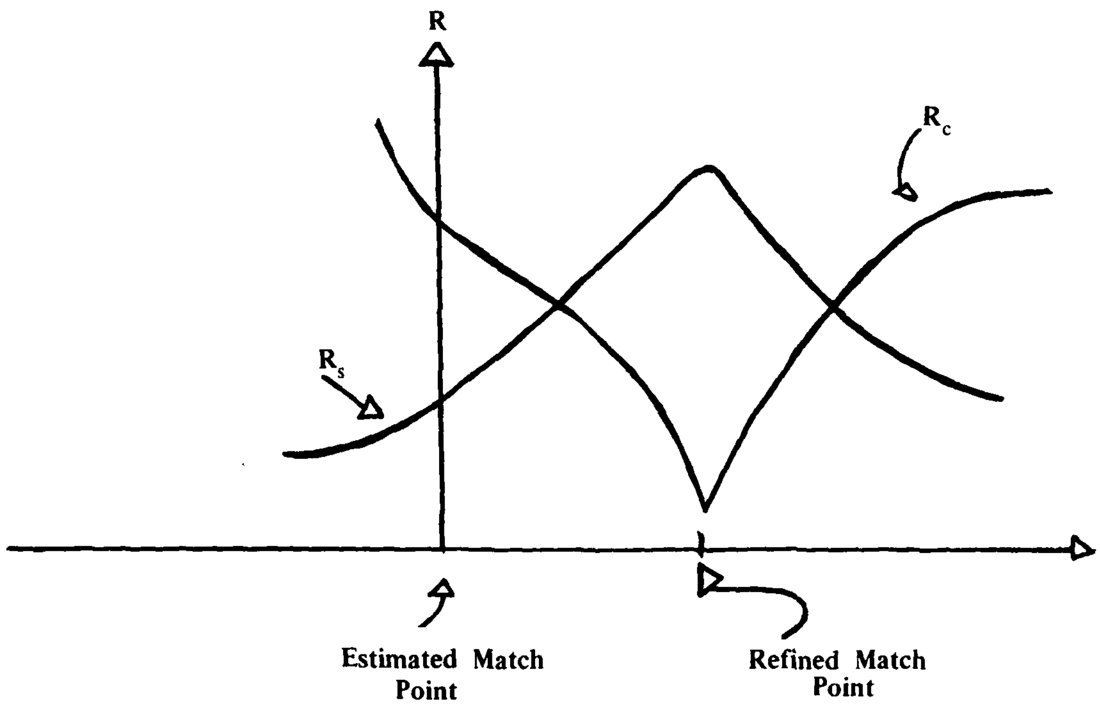


FIGURE 3. Vector Correlation.

The idea underlying figure 3 is that if the structure of the two images is similar, then corresponding gradient vectors will be nearly parallel.

NUMERICAL RESULTS. A set of control points for the evaluation were measured interactively using the DIAL system.[3] The set of control points were measured on scenes A and B (see figures 4 and 5). The set of match point control was organized into three groups; namely,

Group 1	High Signal Power
Group 2	Medium Signal Power
Group 3	Low Signal Power

The evaluation was conducted by matching IR to IR, PANC to PANC, and IR to PANC. The window sizes ranged from 3 to 21 in steps of 2, and match points were determined using all three correlation measures. The effect of geometry was varied by considering several base-height ratios (B/H). The match results were presented in terms of the average deviation (dw) from the control match value:

$$dw = 1/K \sum_{K=1}^{K} \sqrt{(\ell_R - \ell_{cR})^2 + (P_P - P_{cK})^2}$$

where

$$w = \text{window size}$$
$$(\ell_{ck}, P_{ck}) = \text{control point coordinates of } k^{th} \text{ point}$$
$$(\ell_k, P_k) = \text{coordinates determined by image matching}$$

Tables 1 through 7 present averaged deviation values (dw). The sample size (k) for the several tests is listed under the signal power characterization. The units associated with dw are pixel spacings. In this case, the line and sample spacings both equaled 14 μm (micrometers).

From the results in tables 1 through 7, the linear correlation coefficient measure of similarity (R) is superior to the scalar product measure (R_s), which in turn is superior to the absolute value of the vector product (R_c). This is true when similar image types are registered to PANC imagery, as well as when IR imagery is registered to PANC imagery. The results also indicate that window sizes 13 and 15 generally produce the best results for all situations.

[3] L. Gambino and B. Schrock, "An Experimental Digital Interactive Facility," *Computers*, August 1977, pp.22–28.

IR

PANC

FIGURE 4. Scene A.

IR

PANC

FIGURE 5. Scene B.

TABLE 1. Match Results For IR to IR – B/H = 0.6

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
HIGH 6	R_s	3.1	2.7	2.9	1.8	2.8	2.6	1.5	1.5	1.5	1.5
	R_c	5.9	7.3	6.0	6.1	6.1	6.0	6.3	4.1	4.4	5.1
	R	2.5	1.2	1.5	0.8	0.5	0.1	0.2	0.2	0.3	0.4
MEDIUM 5	R_s	6.4	6.0	7.1	6.8	4.6	4.6	5.2	3.0	4.4	4.3
	R_c	4.7	5.8	3.8	3.9	4.9	4.8	3.4	5.7	4.4	6.2
	R	4.1	2.3	1.2	1.0	0.9	0.2	0.0	0.4	0.9	0.9
LOW 6	R_s	4.1	4.0	3.5	3.6	3.6	3.6	3.8	4.0	3.5	4.1
	R_c	4.5	6.3	5.7	6.7	6.1	6.7	6.3	6.6	6.2	6.8
	R	4.3	3.1	2.4	1.8	1.5	1.5	0.4	0.6	0.7	0.5

TABLE 2. Match Results For IR to IR – B/H = 1.2

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
HIGH 6	R_s	3.2	2.7	3.6	3.4	3.2	2.6	2.6	3.2	3.4	3.8
	R_c	6.6	6.4	6.7	7.1	6.6	6.3	4.8	5.7	5.9	5.8
	R	4.5	3.0	1.8	1.0	0.8	0.3	0.3	0.6	0.6	0.6
MEDIUM 5	R_s	4.8	3.6	4.2	5.8	5.1	4.9	5.4	6.3	5.3	5.3
	R_c	6.6	7.0	6.6	5.9	5.7	6.5	6.4	6.5	6.1	5.9
	R	6.1	4.8	4.6	3.5	2.2	1.0	0.8	0.6	1.5	2.3
LOW 6	R_s	5.5	6.6	6.1	6.0	6.0	5.6	3.8	3.7	3.0	1.6
	R_c	5.1	4.7	5.2	3.0	4.7	6.2	6.3	6.2	6.4	6.3
	R	4.5	4.0	3.9	2.0	2.1	1.3	2.5	2.7	3.0	2.1

TABLE 3. Match Results For PANC to PANC – B/H = 0.6

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
HIGH 7	R_s	3.9	3.8	3.4	3.7	2.5	1.9	1.1	2.0	2.0	2.0
	R_c	6.5	5.7	6.3	7.5	7.5	6.9	7.2	7.6	6.2	6.6
	R	3.5	3.1	1.1	0.6	0.5	0.2	0.2	0.3	0.5	0.6
MEDIUM 6	R_s	4.0	4.9	4.5	4.3	3.4	3.0	3.4	3.1	2.8	3.9
	R_c	5.4	6.2	7.0	7.5	7.7	7.2	7.5	8.2	7.7	6.8
	R	5.5	2.8	3.1	2.1	0.8	0.2	0.3	0.5	0.4	0.4
LOW 6	R_s	4.8	4.8	4.3	5.8	5.3	5.2	4.2	5.0	4.7	4.5
	R_c	5.0	3.9	4.0	5.4	6.4	6.0	5.0	5.5	4.9	4.7
	R	5.0	3.7	3.0	2.6	2.2	0.7	1.5	1.3	1.9	2.8

TABLE 4. Match Results for PANC to PANC – B/H = 1.2

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
HIGH 7	R_s	4.4	3.9	3.5	3.2	3.6	3.1	3.6	3.9	4.6	3.4
	R_c	5.6	6.0	5.4	6.7	5.6	6.1	7.1	7.3	7.2	6.6
	R	3.0	3.7	3.4	2.6	2.3	2.0	2.0	2.1	2.2	2.7
MEDIUM 6	R_s	4.8	4.4	5.1	6.2	6.3	3.9	6.1	6.2	5.3	4.6
	R_c	5.6	6.4	6.4	6.4	6.1	6.1	7.0	7.3	7.0	7.2
	R	4.3	4.3	4.8	2.9	2.6	0.8	0.9	1.5	1.1	0.9
LOW 3	R_s	4.2	5.4	4.6	4.7	2.9	2.0	2.3	4.6	5.7	6.4
	R_c	1.9	2.8	3.4	6.0	4.9	6.3	5.8	5.0	4.4	3.2
	R	6.1	3.9	3.4	0.6	0.3	0.2	0.7	4.7	5.0	1.6

TABLE 5. Match Results For IR to PANC – B/H = 0.0

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
HIGH 7	R_s	5.7	4.4	4.1	2.9	3.9	4.1	3.5	5.0	5.2	5.0
	R_c	4.8	5.3	6.1	4.9	6.3	6.7	6.6	6.7	6.2	5.8
	R	5.2	4.3	4.5	4.2	2.5	2.5	1.8	1.6	1.8	2.0
MEDIUM 5	R_s	5.1	5.9	5.5	4.8	1.9	3.4	3.6	3.5	3.8	4.3
	R_c	6.3	5.8	5.9	6.1	6.0	5.0	6.0	6.5	6.8	7.2
	R	5.3	2.2	3.1	1.8	0.6	0.1	0.3	0.5	0.8	0.7
LOW 5	R_s	5.7	4.8	3.7	4.8	4.4	4.6	5.9	6.7	5.1	5.3
	R_c	5.1	5.3	5.9	6.0	6.4	4.8	4.3	4.4	5.7	6.6
	R	2.9	2.7	2.4	2.6	2.5	0.2	0.2	0.5	1.1	1.0

TABLE 6. Match Results For IR to PANC – B/H = 0.6

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
HIGH 7	R_s	5.7	5.7	5.5	4.8	4.3	3.5	4.2	4.5	4.7	4.7
	R_c	5.4	4.5	5.8	5.4	4.7	5.6	5.7	6.8	6.6	5.3
	R	6.0	3.0	2.8	2.3	2.2	2.4	2.2	2.7	2.7	3.0
MEDIUM 6	R_s	5.2	6.0	5.0	5.8	4.9	4.8	4.6	4.7	4.8	5.7
	R_c	5.1	7.7	6.9	7.0	7.3	7.8	7.0	7.2	7.4	7.3
	R	4.5	4.2	4.4	2.4	1.8	1.4	1.3	1.3	1.0	1.2
LOW 5	R_s	4.6	5.9	4.7	4.1	6.5	7.0	4.6	5.8	5.6	5.2
	R_c	6.3	5.0	5.6	7.1	6.0	5.3	5.6	4.6	4.6	5.4
	R	5.6	3.4	2.6	2.3	2.3	1.2	0.2	1.1	1.3	4.2

TABLE 7. Match Results For IR to PANC -- B/H = 1.2

SIGNAL POWER	CORRELATION METHOD	WINDOW SIZE									
		3	5	7	9	11	13	15	17	19	21
HIGH											
4	R_s	5.0	5.2	4.3	5.3	5.4	4.6	3.6	4.1	5.0	4.6
	R_c	4.6	6.8	5.1	4.9	5.0	5.7	6.9	6.9	6.0	5.8
	R	4.1	4.6	5.5	4.6	2.9	4.0	4.0	4.1	4.1	4.4
MEDIUM											
5	R_s	6.1	5.1	5.4	6.4	5.1	5.0	5.4	5.3	4.7	5.1
	R_c	4.8	6.4	5.3	6.6	6.9	7.1	7.3	7.5	7.3	6.0
	R	5.7	3.5	3.9	2.8	1.5	1.5	0.6	0.8	0.6	1.6
LOW											
6	R_s	3.9	5.0	4.6	5.8	4.8	5.3	5.1	6.7	7.2	6.9
	R_c	4.3	3.6	4.0	6.2	6.4	5.5	6.3	6.3	5.9	6.0
	R	5.2	5.0	5.4	4.6	4.0	3.0	4.1	3.3	3.9	3.5

DISCUSSION

As a result, R is a more reliable measure of similarity than either R_s or R_c. Weighted averages of the data in tables 1 through 7 were calculated and are presented in tables 8, 9, and 10. The results in table 8 (match results for R_s) do not vary significantly as the base-height varies or as the window size varies. This observation indicates that the process was generally out of control. Examining a large number of R_s arrays indicated that there were many false maximums, many of which had larger values than the maximum at or near the match point.

The match results in table 9 (match results for R_c) do not vary with base-height, with window size, or with the image pair variations. The process, as with R_s, was generally out of control. Examining a large number of R_c arrays indicated that there were many false minimums, most of which had smaller values then the minimum at or near the match point.

TABLE 8. Match Results For Vector Correlation (R_s)

IR to IR

B/H	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
0.6	4.4	4.1	4.4	3.9	3.6	3.5	3.4	2.8	3.1	3.2
1.2	4.5	4.3	4.7	5.0	4.8	4.3	3.9	4.3	3.8	3.5

PANC to PANC

B/H	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
0.6	4.2	4.5	4.0	4.6	3.7	3.3	2.8	3.3	3.1	3.4
1.2	4.5	4.4	4.3	4.6	4.5	3.2	4.3	4.9	5.1	4.4

IR to PANC

B/H	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
0.0	5.5	5.0	4.4	4.0	3.5	4.0	3.7	5.1	4.8	4.9
0.6	5.2	5.9	5.1	4.9	5.1	4.9	4.4	4.9	5.0	5.2
1.2	4.9	5.1	4.8	5.9	5.1	5.0	4.8	5.5	5.8	5.7

TABLE 9. Match Results For Vector Correlation (R_c)

IR to IR

B/H	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
0.6	5.1	6.5	5.3	5.7	5.8	5.9	5.5	5.5	5.0	6.0
1.2	6.1	6.0	6.1	5.3	5.7	6.3	5.8	6.1	6.1	6.0

PANC to PANC

B/H	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
0.6	5.7	5.3	5.8	6.8	7.2	6.7	6.6	7.1	6.3	6.1
1.2	5.2	5.6	5.4	6.5	5.7	6.1	6.8	6.9	6.6	6.2

IR to PANC

B/H	WINDOW SIZE 3	5	7	9	11	13	15	17	19	21
0.0	5.3	5.5	6.0	5.6	6.2	5.6	5.8	6.0	6.2	6.5
0.6	5.6	5.7	6.1	6.4	5.9	6.3	6.1	6.3	6.3	6.0
1.2	4.6	5.4	4.7	6.0	6.2	6.1	6.8	6.4	6.4	6.0

TABLE 10. Match Results For Conventional Correlation (R)

IR to IR

	WINDOW SIZE									
B/H	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**21**
0.6	3.6	2.2	1.7	1.0	1.0	0.6	0.2	0.4	0.6	0.6
1.2	5.0	3.9	3.4	2.1	1.7	0.9	1.2	1.3	1.7	1.6

PANC to PANC

	WINDOW SIZE									
B/H	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**21**
0.6	4.6	3.2	2.3	1.7	1.1	0.4	0.6	0.4	0.9	1.2
1.2	4.1	4.0	3.9	2.3	2.0	1.2	1.3	2.4	2.3	1.8

IR to PANC

	WINDOW SIZE									
B/H	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**21**
0.0	4.6	3.2	3.5	3.0	1.9	1.1	0.9	1.0	1.3	1.3
0.6	5.4	3.5	3.3	2.3	2.1	1.7	1.3	1.8	1.7	2.7
1.2	5.1	4.4	4.9	4.0	2.9	2.8	2.9	2.7	2.9	3.1

The match results in table 10 (match results for R) vary with base-height and with window size, as expected. A window size of 15 x 15 generally produced the best results for the three image pairs. The results in table 10 also indicate that matching IR to IR produces more accurate results than matching PANC to PANC, which in turn produces more accurate results than matching IR to PANC. In fact, the average error (of a window approximately 15 x 15) when matching IR to PANC for B/H = 0.0 is 1 pixel spacing. The error increases to approximately 1.6 pixel spacing when B/H = 0.6, which is the most useful value of B/H for mapping. The error is approximately 2.8 pixel spacing when B/H = 1.2.

It should be noted that the match process involves pre-processing the imagery to produce gradient images that in turn were matched by using two vector functions as measures of similarity. This is not the same as constructing edge pictures by thresholding either G_ℓ or G_p and then attempting to match the resultant edge pictures.

There are several kinds of problems associated with the gradient matching technique. The resolution of the difficulties would entail extensive image pre-processing that would require detailed knowledge of the imagery. For example, consider the fact that roads are dark on IR; whereas, the same roads are light on PANC, (see figure 6). The gray shade plots represent approximately a 45 meter trace across the road depicted in the upper right corner of figure 5. Note that corresponding gradients in the region of the road are nearly prependicular rather than parallel. This kind of problem could be handled easily if knowledge of the location of roads and objects, such as buildings, existed. This knowledge does not exist since the purpose of the exercise is to determine location.

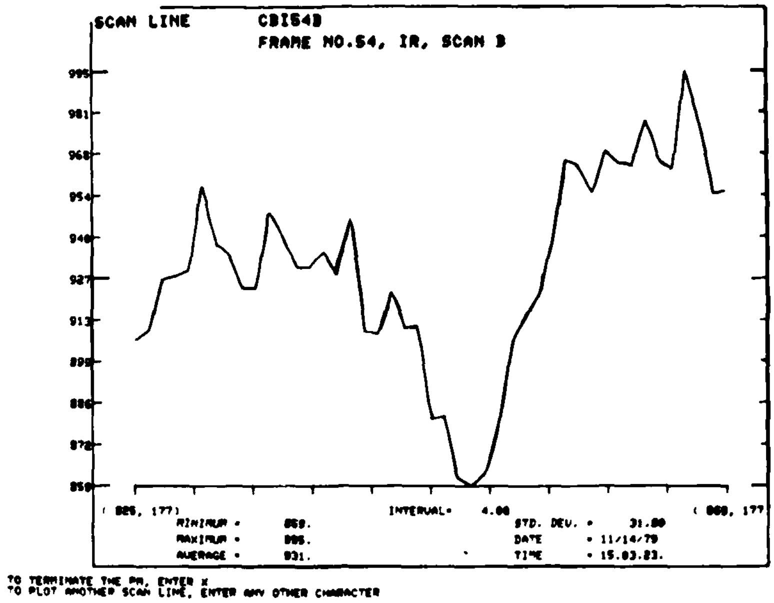
In figures 7 and 8, the difficulties associated with objects appearing on one image and not on the other are shown. The gray shade plots in figure 7 represent approximately a 56 meter trace across the creek shown clearly in the IR of Scene 5, but hardly at all in the PANC of Scene 5.

The gray shade plots in figure 8 represent approximately a 54 meter trace across the field shown in the middle of figure 4. The gray shade peak at the far end of the PANC trace is across the light vertical band that does not appear in the IR.

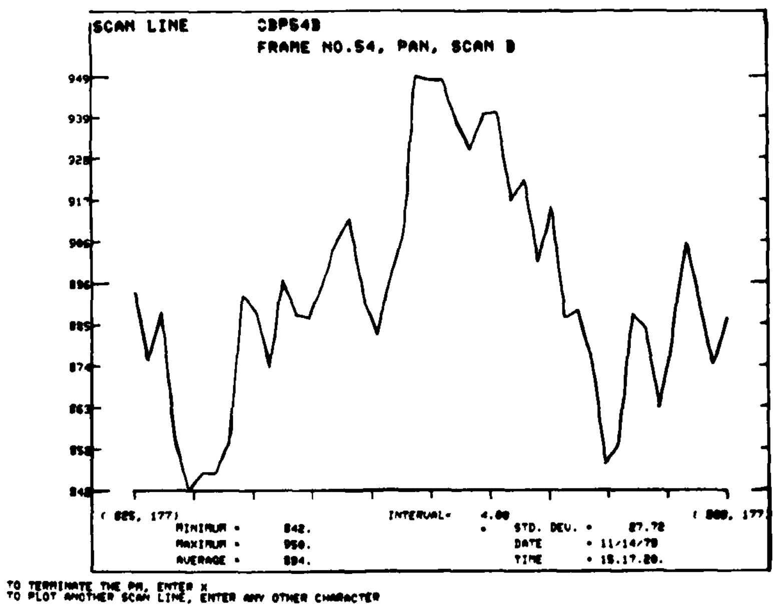
Another problem associated with the gradient vector matching occurs because of highly textured data that appears as noisy data. Data, such as that shown in figures 9 and 10, should be smoothed before the gradients are calculated. Again, before the smoothing takes place, areas designated for smoothing must be determined through photo interpretation. The gray shade plots in figure 9 represent a 48 meter trace across the large field in right center of figure 5. The gray shade plots of figure 10 represent a 64 meter trace across the forest in left center of figure 4.

The various problems addressed above indicated that a successful registration of IR and PANC imagery will require knowledge as to what a pixel is, as well as where it is. This in turn implies that a classification exercise and a matching exercise should be performed concurrently. Such a process was suggested previously.[4] A variety of image features, including point density data, texture data, and edge data from the stereo pair, can be used to develop an algorithm that would include a variety of similarity measures, data structure comparisons, and statistical classification procedures. The several operations could be executed concurrently to resemble more closely a human operation and to produce a more complete set of cartographic information.

[4] M. Crombie and L. Gambino, "Digital Stereo Photogrammetry," Presented to *Congress of the International Federation of Surveyors* (FIG), Commission V, Stockholm, Sweden, June 1977.

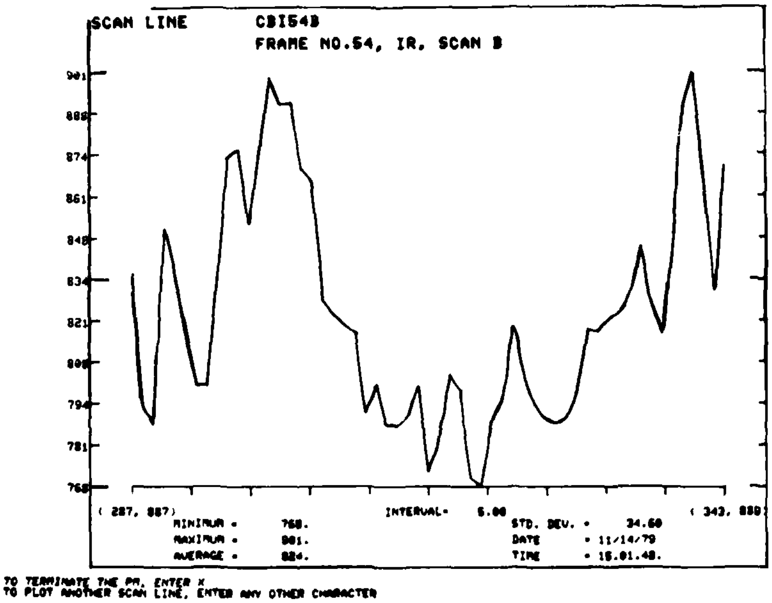


IR

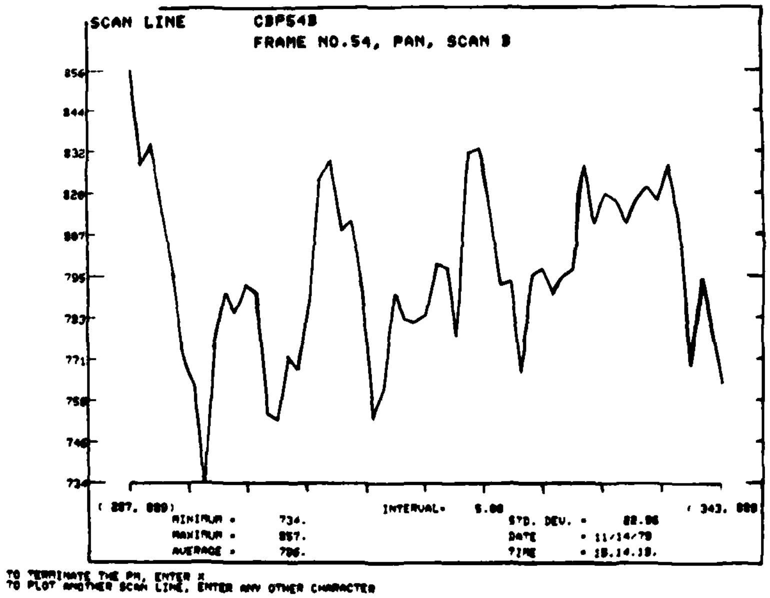


PANC

FIGURE 6. Trace of Road on Scene B.

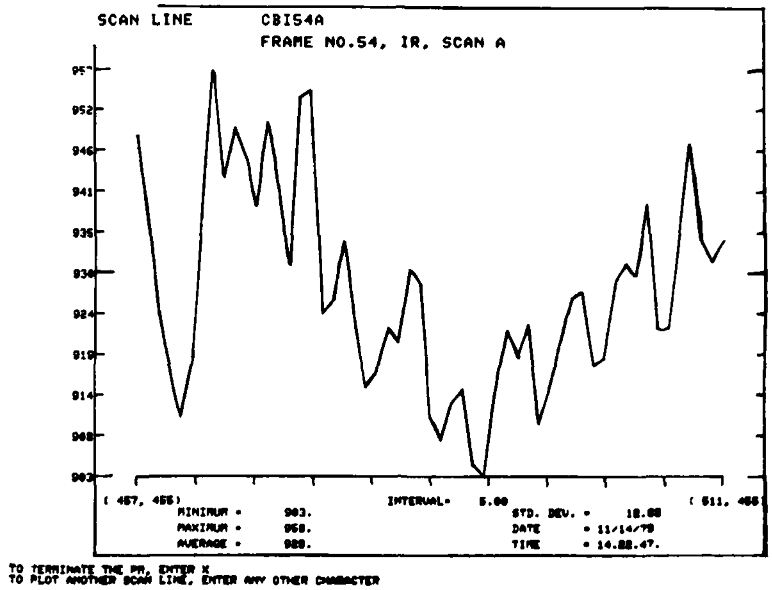


IR

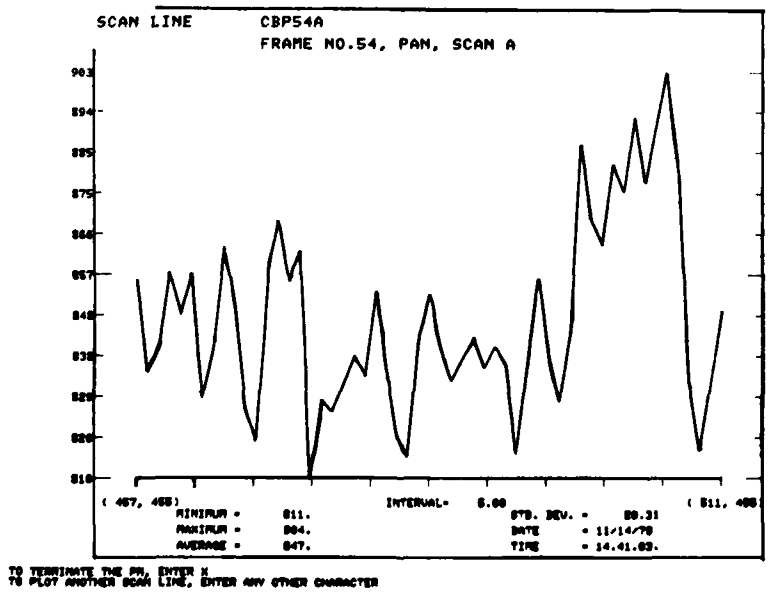


PANC

FIGURE 7. Trace of Creek on Scene B.

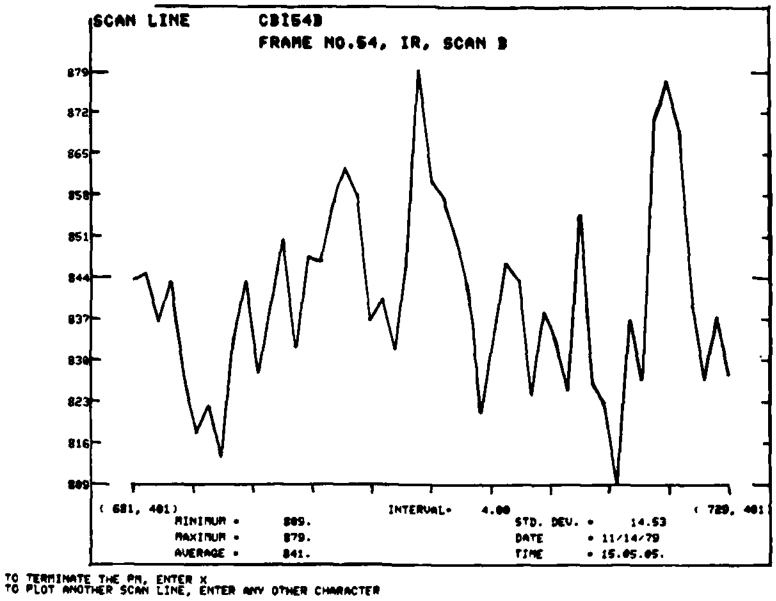


IR

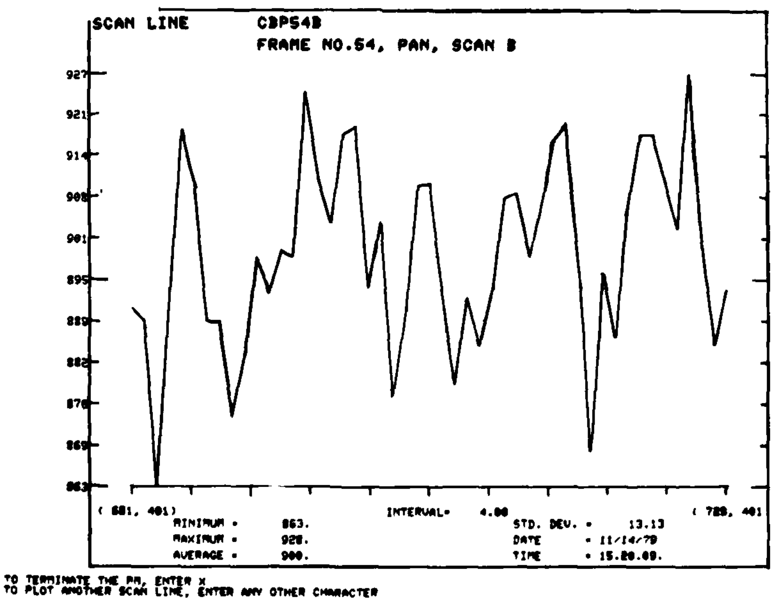


PANC

FIGURE 8. Trace of Field on Scene A.

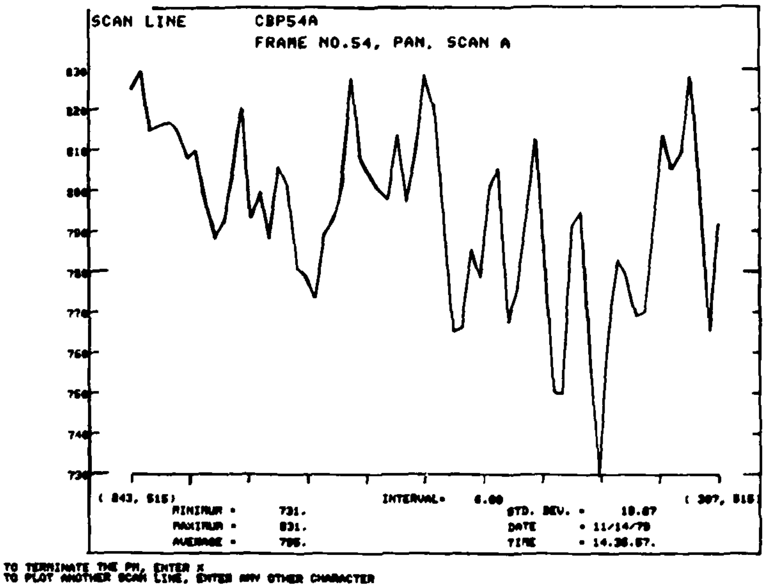


IR

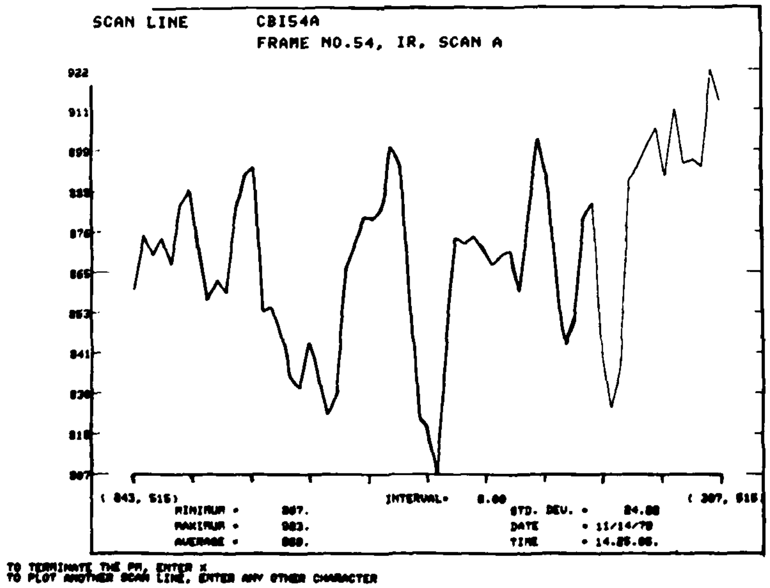


PANC

FIGURE 9. Trace of Field on Scene B.



IR



PANC

FIGURE 10. Trace of Forest on Scene A.

CONCLUSIONS

1. Vector correlation using gradient images is not as accurate as conventional correlation when registering infrared imagery to panchromatic imagery.

2. Vector correlation using gradient images is not suitable for cartographic mapping.

3. IR to IR image matching produces more accurate results then either IR to PANC or PANC to PANC.

4. Classification procedures should be performed concurrently with registration when matching infrared and panchromatic imagery.

5. An algorithm that uses texture data and edge data, as well as point density data, should be developed and tested for the successful registration of IR imagery to PANC imagery.

DATE

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